

**OPTIMIZATION OF RANDOM RUBBLE MASONRY  
RETAINING WALL DESIGN**

A. N. Santhajeewa

(118633P)

Degree of Master of Engineering in Structural Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

April 2015

# **OPTIMIZATION OF RANDOM RUBBLE MASONRY RETAINING WALL DESIGN**

Assurappulige Nalaka Santhajeewa

(118633P)

Dissertation submitted in partial fulfillment of the requirements for the degree  
Master of Engineering in Structural Engineering Design

Department of Civil Engineering

University of Moratuwa

Sri Lanka

April 2015

## DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Date: 8<sup>th</sup> of April 2015

A.N. Santhajeewa

The above candidate has carried out research for the Masters Dissertation under my supervision.

Date: 8<sup>th</sup> of April 2015

Dr. Mrs. D, Nanayakkara

## ABSTRACT

The conventional earth retaining structures built using Random Rubble Masonry (RRM) are designed as gravity retaining structures where weight of the structure is used for its stability. In Sri Lanka, RRM retaining walls is the most common type of retaining structure for low retaining heights. However; in general, engineers are reluctant to adopt RRM for retaining heights more than 3m high, due to comparatively large sections obtained as the result of conventional design practice. More optimal and creative solutions could be obtained even for low retaining heights, if design material properties of RRM are known.

In this study, use of flexural strength of RRM and adopting a Reinforced Concrete (RC) Tie-back at the top of the retaining wall to optimize the conventional design was explored. The experimental investigation was carried out to find out the flexural, compressive and shear strength of RRM. Further, bond strength between Reinforced Concrete (RC) and RRM was investigated. These tests results have been used to ascertain the adoptability of suggested optimizations.

From the experimental study, it was concluded that magnitude of material strengths of RRM are sufficient for considerable optimization by taking into account the effect of flexural strength of RRM and adopting a Tie- back. The width of the base of wall section reduction for 3m high retaining wall was 28% as the result of the optimization.

Keywords: Random Rubble Masonry, Retaining walls, Optimization, Tie- back, Flexural Strength.

## **ACKNOWLEDGEMENT**

There are many individuals who deserve acknowledgement for their contribution towards successful completion of this research.

First, I would like to express my gratitude to my supervisor, Dr. Mrs. D. Nanayakkara for her valuable advice, guidance and assistance throughout the entire period of study. I am much grateful for sharing her vast knowledge and expertise on the field of Masonry.

Secondly, my sincere acknowledgement is towards my employer, Central Engineering Consultancy Bureau for granting me the sponsorship for following the course and other assistances provided for my research works.

I am much grateful to the Head of the Department of Civil Engineering, the Course Coordinator of Master of Structural Engineering, the staff of the Department of Civil Engineering and the staff of the structural laboratory for their valuable guidance and corporation related to all experimental works. The assistance rendered by undergraduate students Buddhi, Maithri and Suresh for experimental works also gratefully acknowledged.

My very special thanks go to my dear wife Mahesha for her continuous encouragement, assistance and patience during the entire period. My research would never be successful without her tremendous support.

Lastly, there are many friends and colleagues who have not been personally mentioned here that I am much indebted to their contribution at various stages of the research to make it successful.

# TABLE OF CONTENTS

Declaration of the Candidate & Supervisors	i
Abstract	ii
Acknowledgements	iii
Table of Contents	iv
List of Figures	viii
List of Tables	x
List of Abbreviations	xi
List of Appendices	xii
<b>1. Introduction</b>	<b>1</b>
1.1 General	1
1.2 Need for Research	2
1.3 Optimization of Gravity Retaining wall	3
1.3.1 Effect of Tie – back	3
1.3.2 Effect of Flexural Strength	3
1.4 Objectives of the Research Study	4
1.5 Methodology	4
1.6 Outline of the Dissertation	5
<b>2. Literature Review</b>	<b>6</b>
2.1 Introduction	6
2.2 Design of Retaining Walls	6
2.2.1 Limit State Design Method	6
2.2.2 Conventional Design Method	7
2.2.2.1 Stability Analysis in Conventional method	7
2.2.2.1.1 Stability Analysis in Craig, R.F [10]	8
2.2.2.1.2 Stability Analysis by Liu,C and Evett, J.B[11]	10
2.3 Adopting Tie back Effect in Gravity Retaining Wall Design	12

2.3.1	Innovative Earth Retaining System Adopted for the Proposed Printing Complex at Mawaramandiya	12
2.3.2	Wall Foundations of Proposed Block no.10- Mahinda Rajapaksha Vidyalaya, Homagama	14
2.4	British Standards relevant to Random Rubble Masonry Design	15
2.5	Standard Construction Practices of Random Rubble Masonry in Sri Lanka	16
2.5.1	Type of Stones	16
2.5.2	Sizes of Stones	16
2.5.3	Dressing of Stones	18
2.5.4	Mortar	18
2.5.5	Mortar Joints	19
2.5.6	Laying	20
2.5.7	Curing	20
2.6	Previous Experimental Investigations on Material properties of Random Rubble Masonry	20
2.6.1	Compressive Strength	20
2.6.2	Shear Strength	21
2.7	Experimental Investigations on Masonry- Concrete Interface	23
<b>3.</b>	<b>Different Approaches used for Design of Random Rubble Masonry</b>	<b>25</b>
3.1	Introduction	25
3.2	Case 1 - Design of RRM Retaining wall using Conventional Method	26
3.3	Case 2 - Retaining Wall assuming RRM will not fail due to flexure	31
3.4	Case 3 – Design of Retaining Wall with the Tie back effect	35
3.5	Summary of the Results obtained from Three Case Studies	41
<b>4.</b>	<b>Experimental Study</b>	<b>43</b>

4.1	General	43
4.1.1	Preparation of Test Specimens	44
4.2	Experimental Set-up	45
4.2.1	Testing for Flexural Strength of RRM	45
4.2.2	Testing for Shear Strength of RRM	47
4.2.3	Testing for Shear Strength at Concrete- RRM Interface	49
4.2.4	Testing for Compressive Strength of RRM	51
<b>5.</b>	<b>Analysis of Test Results</b>	<b>52</b>
5.1	Flexural Strength	52
5.1.1	Experimental Results	52
5.1.2	Evaluation of Results	56
5.1.3	Comparison of Test Results with Brick/ Block Masonry Flexural Strengths	58
5.2	Shear Strength	59
5.2.1	Experimental Results	59
5.2.2	Evaluation of Results	61
5.2.3	Comparison of Results with previous research findings	64
5.3	Shear Strength at Concrete- RRM interface	64
5.3.1	Experimental Results	64
5.3.2	Evaluation of Results	67
5.3.3	Comparison of Results with previous research findings on Shear strength at Concrete- Masonry interface	68
5.4	Compressive Strength	69
5.4.1	Experimental Results	69
5.4.2	Evaluation of Results	69
5.4.2.1	Compressive Strengths of each Sample	69
5.4.2.2	Mean Compressive Strength	70
5.4.2.3	Characteristic Compressive Strength	71



5.4.3	Comparison of Results with previous research findings on Compressive Strength of RRM	71
5.5	Summery of Test Results obtained by the Experimental Study	72
<b>6.</b>	<b>Conclusions and Recommendations</b>	<b>73</b>
6.1	Use of Experimental Results for the improvements of RRM Retaining wall Design	73
6.1.1	Flexural Strength	74
6.1.2	Effect of Tie back	74
6.2	Suggestions for Future Works	75
	Reference List	77
	Appendix A	79
	Appendix B	81
	Appendix C	82
	Appendix D	83
	Appendix E	84

## LIST OF FIGURES

		Page
Figure 1.1	RRM retaining wall in front of Nuwara Eliya Post Office	2
Figure 1.2	Application of Tie-back for RRM retaining walls	3
Figure 2.1	Loads and base reactions of retaining walls	8
Figure 2.2	Modified RRM retaining wall system adopted	13
Figure 2.3	Construction of Tie back arrangement at the site	13
Figure 2.4	Wall foundations at the rear side of the class block	14
Figure 2.5	Typical bond patterns and Specifications for Bushing, amount of Chips and through stone	17
Figure 2.6	Types of Stones used in RRM	18
Figure 2.7	Types of Joints used in RRM	19
Figure 2.8	Triplet setup by Milosevic J. [17]	22
Figure 2.9	Relationship between Normal stress and Shear stress of samples	23
Figure 2.10	(a): Testing Setup	24
	(b): Shear deformation while applying the load	24
Figure 3.1	Loadings acting on Retaining wall for Case 1	26
Figure 3.2	Loadings acting on Retaining wall for Case 2	31
Figure 3.3	Assumed Base Pressure Variation for Case 2	33
Figure 3.4	Loadings acting on Retaining wall for Case 3	36
Figure 3.5	Possible Shear Failure Planes of RRM for Case 3	40
Figure 4.1	(a): Preparing samples for Flexural Strength Test	44
	(b): Pre-Compressed Specimens	45
Figure 4.2	(a): The Plane of Bending is Vertical	45
	(b): The Plane of Bending is Horizontal	45
Figure 4.3	The test set up for Specimens bent about Vertical Axis (Plane of Bending is horizontal)	46
Figure 4.4	The test set up for Specimens when the plane of bending is vertical	46
Figure 4.5	Set up for Triplet tests as in [3]	47

	Page	
Figure 4.6	Set up adopted for Shear Strength Test	48
Figure 4.7	Test set up for Shear Strength Test	49
Figure 4.8	Set up for investigating Shear Strength at Concrete-RRM Interface Test	50
Figure 4.9	Set up for Compressive Strength Test	51
Figure 5.1	Failure patterns of Specimens (When the Plane of Bending is horizontal)	
	(a): Specimen 1	53
	(b): Specimen 2	53
	(c): Specimen 3	53
Figure 5.2	Failure Patterns of Specimens (When the Plane of Bending is Vertical)	
	(a): Specimen 4	54
	(b): Specimen 5	55
	(c): Specimen 6	55
Figure 5.3	(a): Failure Patterns of Specimens – Specimen 1	59
	(b): Failure Patterns of Specimens – Specimen 2	59
	(c): Failure Patterns of Specimens – Specimen 3	60
	(d): Failure Patterns of Specimens – Specimen 4	60
	(e): Failure Patterns of Specimens – Specimen 5	60
	(f): Failure Patterns of Specimens – Specimen 6	60
Figure 5.4	Variation of individual Shear Strength values with the Pre-Compressive Stresses	62
Figure 5.5	Failure Pattern of Specimens for Shear Test	
	(a): Specimen 1	65
	(b): Specimen 2	65
	(c): Specimen 3	66
	(d): Specimen 4	66
	(e): Specimen 5	66
	(f): Specimen 6	66

## LIST OF TABLES

	Page	
Table 2.1	Summary of guidance on British and British European Standards relevant to Natural Stone	15
Table 2.2	Characteristic Compressive Strength of RRM for Mortar designation of 1:5	21
Table 2.3	Comparison of Characteristic Compressive Strength of RRM and Brick work for Mortar designations of 1:5 and 1:8	21
Table 3.1	Summary of results obtained from Three Case Studies	41
Table 5.1	Results of the test on Flexural Strength (When the Plane of Bending is horizontal)	52
Table 5.2	Results of Flexural Strength Test (When the Plane of Bending is Vertical)	54
Table 5.3	Flexural Strength of RRM specimens	56
Table 5.4	Characteristic Flexural Strength of RRM	57
Table 5.5	Flexural strength of Brick and Block Masonry as per BS 5628-1:1992	58
Table 5.6	Results of the Test on Shear Strength	59
Table 5.7	Shear Strength results for different Pre-Compressive Stresses	62
Table 5.8	Results of Shear Strength Test	65
Table 5.9	Results of test carried out for Shear Strength at Concrete-Masonry Interface	68
Table 5.10	Results of Compressive Strength Test	69
Table 5.11	Compressive Strength Results of each sample	70
Table 5.12	Characteristic Compressive Strength of RRM for Mortar designation of 1:5	71
Table 5.13	Summary of Strength Parameters of RRM	72
Table 6.1	Results obtained through different Design Approaches	73
Table 6.2	Extent of Optimization for 1-3m Retaining Heights	75

## **LIST OF ABBREVIATIONS**

Abbreviation	Description
RRM	Random Rubble Masonry
RC	Reinforced Concrete
BS	British Standard
ICTAD	Institution of Construction Training & Development
HM	Hydraulic Mortar
AM	Air Lime Mortar
ASTM	American Society for Testing and Materials

## LIST OF APPENDICES

Appendix	Description	Page
Appendix – A	Flexural Strength -Experimental Data and Results	79
Appendix – B	Shear Strength -Experimental Data and Results	81
Appendix – C	Shear Strength at Concrete Masonry Interface – Experimental Data and Results	82
Appendix – D	Compressive Strength – Experimental Data and Results	83
Appendix – E	Calibration Reports of Proving Rings	84